DSP-free and real-time NRZ transmission of 50Gb/s over 15km SSMF and 64Gb/s back-to-back with a 1.3µm VCSEL

M. Verplaetse[1], L. Breyne[1] , Christian Neumeyr[2], Timothy De Keulenaer[3], Wouter Soenen[3], X. Yin[1], P. Ossieur[1], G.Torfs[1], J. Bauwelinck[1]

[1]IDLab, INTEC, Ghent University - imec, 9052 Ghent, Belgium, [2]Vertilas GmbH, Daimlerstrasse 11d, 85748 Garching, Germany
[3]BiFast, Spin-off of Ghent University-imec, IDLab, 9052 Ghent, Belgium
**E-mail: michiel.verplaetse@ugent.be*

Abstract: We demonstrate DSP-free and real-time NRZ transmission at 50Gb/s over 15km SSMF, 60Gb/s over 5km SSMF and 64Gb/s back-to-back using a directly modulated 1326nm short cavity VCSEL supported by a SiGe BiCMOS 6-tap feedforward equalizer.

OCIS codes: (200.4650) Optical Interconnects; (060.2360) Fiber optics links and subsystems

1. Introduction

Data centers, which underpin ever more popular internet applications such as cloud computing, search engines and social media need to handle a rapidly increasing amount of information. This has put the links inside and between data centers under significant pressure, pushing industry and academia to develop solutions for 400G and beyond optical links [1] and a successor technology for today's cost efficient multimode VCSELs. Fiber reaches for these applications range from 100m up to 2km for intra data center links and at least 10km for inter data center links. While many proposed solutions rely on external modulation implemented in III-V or Silicon Photonics material systems [2,3], links based on directly modulated VCSELs have the potential to provide low power, low cost and low complexity solutions [4-10]. In [4-6], short wavelength multimode VCSELs were reported that achieve bitrates as high as 100Gb/s. However, with these links, it is difficult to achieve reaches beyond 200m at rates higher than 50Gb/s without extensive digital signal processing (DSP). This has spurred interest in long wavelength single-mode VCSELs. Long wavelength VCSELs, based on Indium Phosphide (InP) as base material, feature a high bandwidth, extremely low power consumption and offer cost effective solutions at 1.3µm (O-Band) to 1.55µm (C- and L-Band). In [7-9], several C-band VCSELs and links were reported, with a >20GHz bandwidth VCSEL in [9]. However, transmission in the C-band is limited by chromatic dispersion in standard single-mode fiber (SSMF) and hence O-band VCSELs are promising to achieve a higher bitrate x distance product. In [10], a directly modulated link using a 1325nm VCSEL is reported, capable of reaching 28Gb/s using NRZ over 20km and 40Gb/s over 4.5km. Link performance is limited by the bandwidth of the O-band VCSEL, which is still less compared to state of the art C-band VCSELs. A further increase in speed for VCSEL based links can be achieved using equalization or multilevel modulation techniques such as 4-level pulse amplitude modulation (PAM4). For example in [7], the authors relied on high-speed digital-to-analog converters (DACs), analog-to-digital converters (ADCs) and DSP to realize 28Gbaud PAM4 transmission over 15km SSMF up to 42Gbaud over 1km SSMF using a C-band VCSEL. However, the need for DACs, ADCs and DSP increases cost, complexity and power consumption of the transceivers.

Therefore, here we demonstrate a link using the same O-band VCSEL from [10], now combined with a transmit-side analog 6-tap feedforward equalizer (FFE), without relying on any DSP. Bit-error rates (BERs) were measured in real-time (without any offline processing) and no optical amplification was used to overcome link losses.

2. Experimental Setup

The O-band VCSEL used in this work is a single mode short-cavity VCSEL, developed by Vertilas, based on an InP Buried Tunnel Junction design with a maximum modulation bandwidth up to 17GHz at room temperature [10]. The biasing current and high speed signals are delivered to the VCSEL using an RF microprobe and bias-T. The light was coupled into the fiber via a lensed fiber probe. At a bias current of 12mA, the VCSEL emits light at 1326.2nm with an optical power of 4.7dBm. The PI and VI curves measured at room temperature are shown in Fig. 2. A low threshold current of 2mA and maximum output power of 3.4mW can be seen. At 12mA (14mA) bias current, the VCSEL consumes 20.1mW (24.7mW) electrical power.

The optical link and measurement setup is shown in Figure 1. Four 2^7 -1 bits long pseudo-random bitstreams (PRBS) are generated on FPGA and multiplexed into a serial 2^7 -1 bits PRBS stream by applying appropriate delays. Afterwards, this serialized signal is pre-equalized using an analog 6-tap FFE [11]. Both the multiplexing and equalization are implemented on the same transmitter IC together with a 50Ω driver capable of generating approximately 300mVpp single-ended signals. The IC is fabricated in a 55nm SiGe BiCMOS technology and consumes ~0.85W. To increase the signal swing, a combination of a broadband amplifier and attenuator are used to obtain a broadband amplification of 14dB (with a 3dB bandwidth of 50GHz), resulting in a single-ended signal swing of approximately 1.35Vpp. This extra gain stage and the biasing could be included in future iterations of the TX IC. The amplified signal is used to directly modulate the VCSEL and is applied using a bias-T. The eye diagram of the 50Gb/s drive signal, optimized for B2B communication, is shown in Fig. 1. The overshoot required to compensate the bandwidth limitations in the link can be clearly seen. An optical isolator is added to the link to prevent back reflections that could disturb directly modulated lasers. A variable optical attenuator is used to control the optical power incident on the photoreceiver. A commercial linear PIN differential photoreceiver (DSC-R409-LW from Discovery Semiconductors, Inc) with a bandwidth of 31GHz and a conversion gain of 159V/W is used to capture the optical signal**.** The received signal is sampled in a custom RX IC capable of receiving NRZ signals upto 100Gb/s. The signal is then deserialized with a 1:4 demultiplexer on chip. One of the 4 streams is fed back to the FPGA for real-time BER measurements without any DSP or offline processing. The RX IC is fabricated in a 130nm SiGe BiCMOS technology and consumes about 1.2W and can be used for communication up to 100Gb/s NRZ [2].

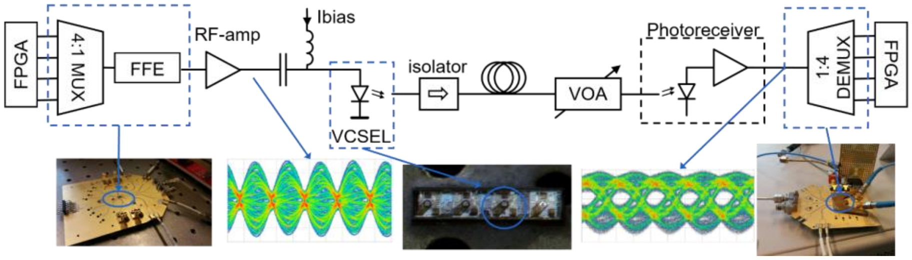

Fig. 1: Experimental setup for the O-band optical link (50Gb/s eye diagrams, transmit eye optimized for B2B communication)

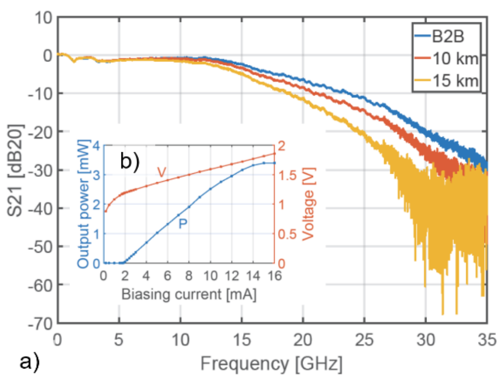

Fig. 2: Normalized S-parameters of the opto-electrical link at different transmission distances over SSMF with a VCSEL bias of 12mA (a), DC characteristics of the VCSEL (b).

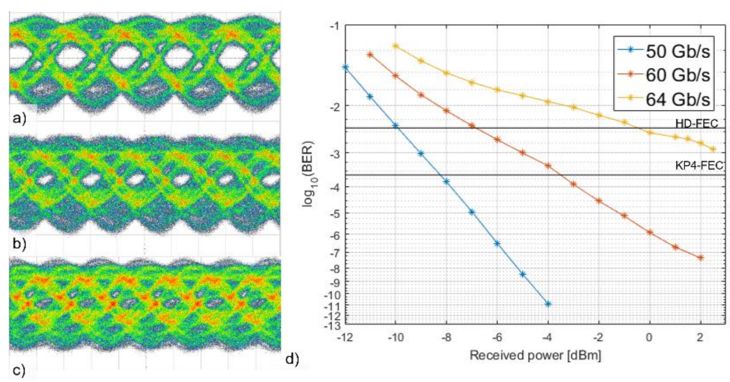

Fig. 3: Received eye diagrams at 0dBm received optical power (40mV-10ps/div, measured with a 70GHz sampling scope) for B2B communication at 50Gb/s (a), 60Gb/s (b) and 64Gb/s (c). Real time BER curves for B2B communication (d).

The small-signal frequency response of the opto-electrical link (without FFE and RF-amp) for different lengths of SSMF can be found in Fig. 2. In the back-to-back (B2B) case, a 3-dB bandwidth of 15.5 GHz is observed dropping to 12GHz at 15km SSMF due to the combination of SSMF chromatic dispersion at 1326nm and VCSEL chirp. This shows that the main bandwidth limitation at short distances is due to the VCSEL modulation bandwidth and at longer distances due to the combination of chromatic dispersion and VCSEL chirp.

3. Results and Discussion

To evaluate the link performance, real-time BER measurements are performed with the system shown in Figure 1. First, B2B measurements are performed at different rates. The resulting BER curves as a function of received average optical power (controlled by the VOA) are shown in Figure 3. For each rate, the FFE parameters are optimized to reach the minimum BER when the VOA is set to its minimal attenuation, and are then fixed for the remainder of the BER curve. For the 50Gb/s experiments, the minimal BER was achieved with a VCSEL bias current of 12mA, for 60 and 64Gb/s experiments 14mA was used. There is around 2dB insertion loss in the optical link (B2B), resulting in a maximum received power of 2.7dBm (3.1dBm) at a bias current of 12mA (14mA). For 50Gb/s, error free operation is possible (no errors after transmitting $1x10^{13}$ bits) for received optical powers exceeding -4 dBm, which results in an error free link margin of at least 5.7 dB. At 60Gb/s, a minimum BER of $4.4x10^{-8}$ is obtained at 2dBm of received optical power. Assuming RS(544,514) feedforward error correction (FEC), the pre-FEC BER is $2.4x10^{-4}$ (KP4-FEC), at which value a penalty around 5dB is present with respect to 50Gb/s. At 64Gb/s, a minimum BER of $1.24x10^{-3}$ is obtained at 2.5dBm of optical receiver power. At a pre-FEC BER of $3.8x10^{-3}$, assuming a 7%-OH HD-FEC (HD-

FEC), a penalty around 10dB is present with respect to 50Gb/s and 7dB with respect to 60Gb/s, attributed to increased eye closures at these rates.

In Fig. 4, the BER vs. received average power for different SSMF lengths is shown. The frequency responses of the corresponding links can be found in Fig. 2a. At 50Gb/s, transmission over 10km is obtained with a minimum BER of $2x10^{-12}$. At HD-FEC and KP4-FEC, a power penalty around 1dB is observed with respect to the B2B case. For transmission over 15km SSMF, a minimal BER of $3x10^{-4}$ is observed at an optical received power of -3.1dBm (VOA removed to obtain minimal insertion loss). Due to the additional attenuation from the long fiber with respect to the B2B operation, a lower BER is not possible. At the HD-FEC threshold, a penalty of 4dB is present with respect to the B2B transmission. At 60 Gb/s, transmission over 2 and 5km of SSMF are performed leading to a minimum BER of $8.2x10^{-6}$ (below KP4-FEC) and $2.7x10^{-3}$ (below HD-FEC) respectively. A power penalty of 2dB (HD-FEC and KP-FEC) for 2km is present while at 5km, a penalty of 7dB (HD-FEC) is measured. The power penalties are attributed to the combination of VCSEL chirp and fiber chromatic dispersion (as the VCSEL emission wavelength was not exactly at the zero dispersion wavelength), leading to bandwidth reduction (see Fig. 2a).

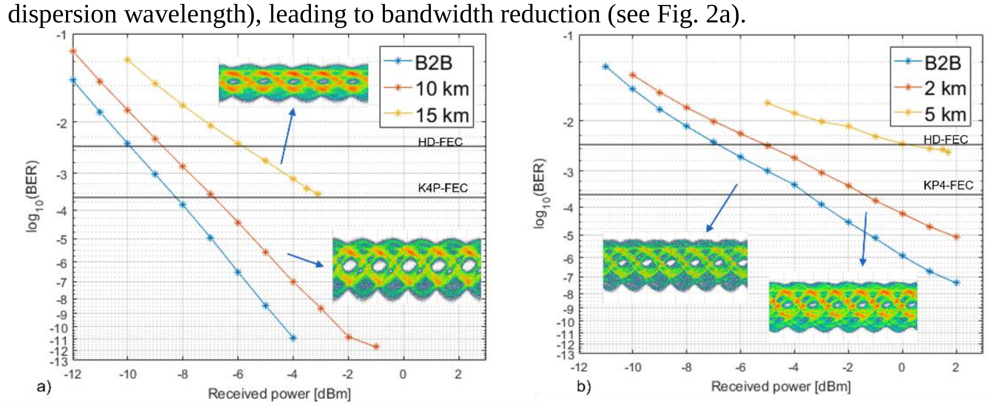

Fig. 4: Real time BER curves and eye diagrams for transmission experiments at (a) 50Gb/s and (b) 60Gb/s

4. Conclusion

We have demonstrated an O-band NRZ-OOK DSP-free link based on a single-mode short-cavity InP VCSEL emitting at 1326nm, supported with an in-house designed transmit-side 6-tap analog feedforward equalizer. At 50Gb/s, transmission over 10km is shown with minimum BER of $2x10^{-12}$ and transmission up to 15km with a BER below 7%-OH HD-FEC (BER=$3.8x10^{-3}$) is achieved which is the longest real-time (no offline processing) O-band VCSEL based link at 50Gb/s reported so far. The transmission over 15km SSMF shows the potential to use VCSELs for inter data center interconnects links and provides a viable alternative for the 400GBase-LR8 standard [1]. At 60Gb/s, transmission up to 5km SSMF with a BER below HD-FEC is demonstrated, proving that O-band VCSELs can be used for intra data center distances. This is the longest real-time O-band VCSEL based link at this speed. At 64Gb/s, transmission with a BER below HD-FEC was measured which is the fastest real-time O-band VCSEL link up to this point.

This work was supported by the UGent IOF for the Tx/Rx ICs, Special Research Fund (BOF), the FWO and the EU FP7 project RAPIDO for the development of the VCSEL.

5. References

[1] "IEEE P802.3bs 400 Gigabit Ethernet Task Force," Jul. 15, 2017. [Online]. Available: http://www.ieee802.org/3/bs/.

[2] J. Verbist et.al., "Real-time 100Gb/s NRZ and EDB transmission with a GeSi electroabsorption modulator for short-reach optical interconnect", JLT., vol. 36, pp. 90-96, Jan. 2018.

[3] J. Zang et.al., "EML-based IM/DD 400G (4x112.5-Gbit/s) PAM-4 over 80km SSMF based on linear pre-equalization and nonlinear LUT pre-distortion for inter-DCI applications", OFC 2017, paper W4I.4.

[4] J.M. Castro et.al., "Investigation of 60Gb/s 4-PAM using an 850nm VCSEL and multimode fiber", JLT, vol. 34, pp. 3825-, Aug. 2016.

[5] J. Lavrencik et.al., "4λ x 100Gbps VCSEL PAM-4 transmission over 105m of wide band multimode fiber", OFC 2017, paper Tu2B.6.

[6] T.N. Huynh et.al., "4x50Gb/s NRZ shortwave-wavelength division multiplexing VCSEL link over 50m multimode fiber", OFC 2017, paper Tu2B.5.

[7] N. Eiselt et.al., "Experimental demonstration of 56Gbit/s PAM-4 over 15km and 84Gbit/s PAM-4 over 1km SSMF at 1525nm using a 25G VCSEL", European Conference on Optical Communication, pp. 971-973, Sept. 2016.

[8] D.M. Kuchta et.al., "Error-free 56Gb/s NRZ modulation of a 1530nm VCSEL link", ECOC 2015, paper ID 1023.

[9] S. Spiga et.al., "Single-mode 1.5-μm VCSELs with 22-GHz small-signal bandwidth", OFC 2016, paper Tu3D.4.

[10] A. Malacarne et.al., "Optical transmitter based on 1.3μm VCSEL and SiGe Driver Circuit for Short Reach Applications and beyond", JLT, 2017.

[11] M. Verplaetse et.al., "Adaptive Transmit-Side Equalization for Serial Electrical Interconnects at 100 Gb/s Using Duobinary", IEEE TCAS I, vol. 64, pp. 1865-1876, July 2017.

OSA | The Optical Society
OSA Publishing

Options

© 2018 OSA

Optical Fiber Communication Conference 2018
San Diego, California United States
11–15 March 2018
ISBN: 978-1-943580-39-2

From the session
Postdeadline Session II (Th4B)

DSP-free and real-time NRZ transmission of 50Gb/s over 15km SSMF and 64Gb/s back-to-back with a 1.3u m VCSEL

Michiel Verplaetse, Laurens Breyne, Christian Neumeyr, Timothy De Keulenaer, Wouter Soenen, Xin Yin, Peter Ossieur, Guy Torfs, and Johan Bauwelinck

Author Information

Optical Fiber Communication Conference Postdeadline Papers OSA Technical Digest (online) (Optical Society of America, 2018), paper Th4B.7 • https://doi.org/10.1364/OFC.2018.Th4B.7

Email
Share

Get Citation
Get PDF (511 KB)
Set citation alerts
Save article

Related Topics

Optics & Photonics Topics
Vertical cavity surface emitting lasers

Previously assigned OCIS codes
Fiber optics links and subsystems (060.2360)
Optical interconnects (200.4650)

Not Accessible
Your account may give you access

Abstract

Abstract

We demonstrate DSP-free and real-time NRZ transmission at 50Gb/s over 15km SSMF, 60Gb/s over 5km SSMF and 64Gb/s back-to-back using a directly modulated 1326nm short cavity VCSEL supported by a SiGe BiCMOS 6-tap feedforward equalizer.

© 2018 OSA

PDF Article

Optical Fiber Communication Conference 2018 San Diego, California United States 11–15 March 2018 ISBN: 978-1-943580-39-2

From the session Postdeadline Session II (Th4B)

Home

My Favorites

To Top

Recent Pages

Previous Article

Next Article

Journals

Proceedings

- By Year
- By Name

Regional Sites

OSA Publishing China

Information for

Authors

Reviewers

Librarians

Open Access Information

Open Access Statement and Policy

Terms for Journal Article Reuse

Other Resources

OSAP Bookshelf

OIDA Reports

Optics & Photonics News

Optics ImageBank

Spotlight on Optics

Regional Sites

OSA Publishing China

About

About OSA Publishing

About My Account

Contact Us

Send Us Feedback

© Copyright 2018 | The Optical Society. All Rights Reserved

Privacy | Terms of Use